Target Physics Issues for Inertial Fusion Energy*

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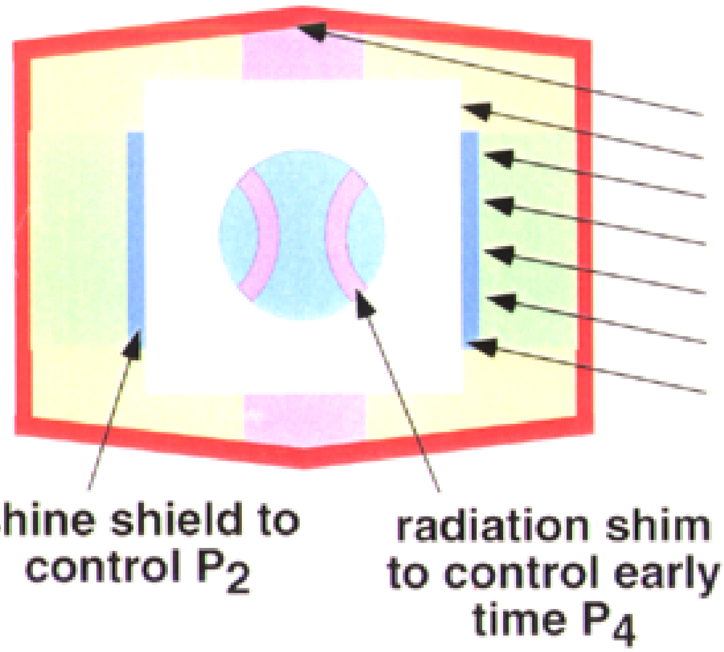
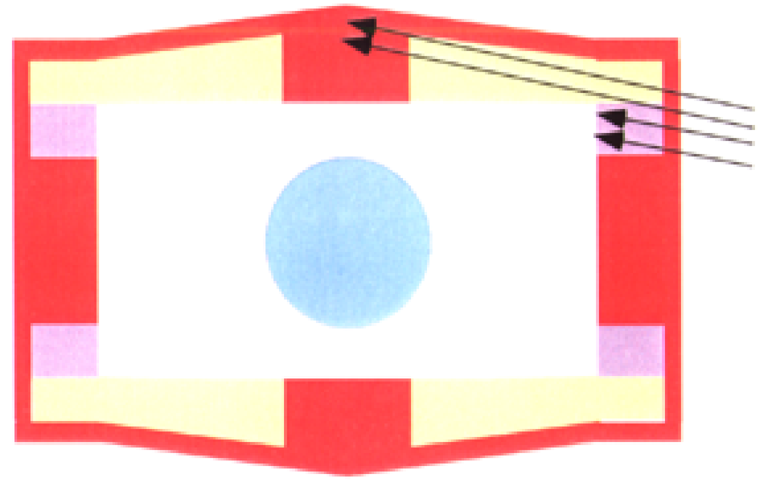
We are using internal hohlraum shields to develop distributed radiator targets with larger beam spots





original distributed radiator target

Beam spot: 3.8 mm x 5.4 mm
Effective radius: 4.5 mm

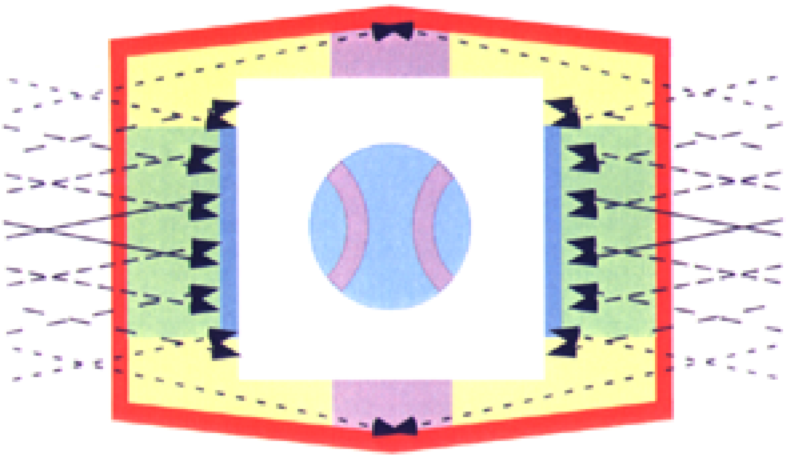
6.7 MJ beam energy
Gain = 58

Beam spot: 1.8 mm x 4.1 mm
Effective radius: 2.7 mm

5.9 MJ beam energy
Gain = 68

66% increase in beam radius with a 14% increase in beam energy

The new hybrid target faced major design challenges

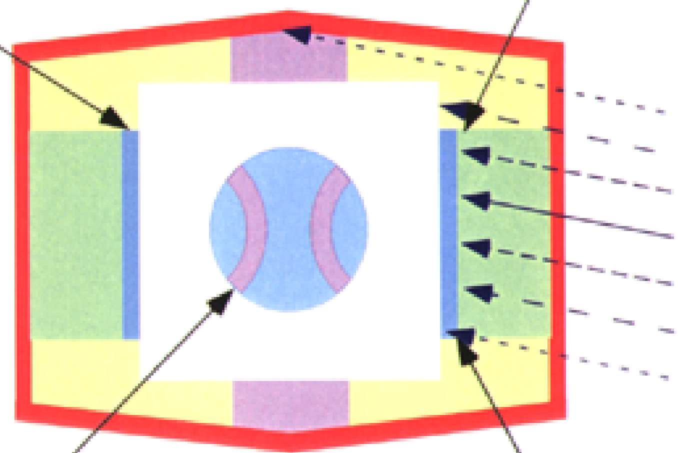


- For Gaussian beams, >50% of the energy is deposited behind the shine shield
  - Transport losses and lack of symmetry control are major issues
- Not enough energy is deposited over the capsule waist to control P_2 symmetry
- This results in a large P_4 source above the shine shield
  - A radiation shim is used to correct for this asymmetry

The new hybrid target introduces some new target physics issues

radiation transport through and around semi-transparent shine shield effects symmetry

hydrodynamic motion of the shine shield and the converter behind it effects ion stopping and radiation transport



radiation shim and its effect Rayleigh-Taylor instability growth--can it be moved off the capsule?

ion range in a plasma must be known to prevent straggling ions from hitting the capsule

These issues can be addressed in experiments with existing ion beams (GSI, Germany), lasers or Z-pinches (Omega, Z), or future ion beams

The Rosseland Mean Opacity of a Mixture of Gold and Gadolinium at High Temperatures

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Radiation transport through high-opacity materials can be described using the Rosseland mean opacity of the medium, which is dominated by low-opacity regions in the frequency-dependent opacity. By mixing gold and gadolinium, we can fill in low-opacity regions of one material with high-opacity regions of another material, resulting in a material with a Rosseland mean opacity 1.5× higher than either of the constituents. For a given laser energy, this can raise the temperature of the laser heated hohlraums, or for a given desired temperature, require less laser energy. [S0031-9007(96)01422-6]

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In the indirect drive approach [1] to inertial confinement fusion [2] the radiation that drives the implosion of the fuel capsule is generated by the interaction of intense beams, either lasers [3] or particles [4], with the interior walls of a high-Z cavity, or hohlraum. This radiation is typically described by a blackbody spectrum with a temperature of about 250 eV. This high temperature radiation not only drives the fuel pellet compression, but also heats and ablates the hohlraum wall. The interaction of the radiation with the hohlraum wall is characterized by multiple absorption and reemission of the x rays [5–7]. The ratio of the reemitted flux to the incident flux is referred to as the albedo α. The efficiency with which the radiation couples to the capsule depends on the albedo; increasing the albedo improves the coupling efficiency. The incident flux is the sum of the reemitted flux plus the x-ray flux lost to the wall. This flux lost to the wall propagates through the wall in the form of a (diffusive) ablative heat wave [8]. The rate of diffusion is (approximately) inversely proportional to the square root of the Rosseland mean opacity. Increasing the Rosseland mean opacity reduces the radiation energy lost to the walls and thus increases the albedo. Hence for a given laser power (and x-ray conversion efficiency) the drive temperature increases as does the coupling efficiency of the radiation to the fuel pellet.

The Rosseland mean opacity [9] is used to describe radiation transport in optically thick materials when the matter and radiation are in thermodynamic equilibrium. It is defined as a weighted harmonic mean of the energy dependent opacity:

$$\frac{1}{\kappa_R} = \frac{\int_0^\infty \kappa_\nu^{-1}(\partial B_\nu/\partial T)\,d\nu}{\int_0^\infty (\partial B_\nu/\partial T)\,d\nu}. \tag{1}$$

Here T is the radiation and material temperature, B_ν is the blackbody spectrum, and κ_ν is the frequency-dependent opacity. This mean opacity is dominated by the regions of low opacity in the frequency-dependent opacity.

Typically we use pure Au hohlraums, heated to a temperature of ~250 eV. An energy-dependent opacity for Au at a density and temperature relevant to these experiments is shown in Fig. 1. This opacity was calculated using a very simple average atom model [10] for Au at 1.0 g/cm^3 and a temperature of 250 eV. There are significant windows in the opacity at energies around the peak of the blackbody spectrum. The gross structure of the opacity shown in Fig. 1 is dominated by the bound-free (photoelectric) absorption coefficient: the sharp increases in opacity correspond to the photoionization of the various atomic shells ($K, L, M, \ldots$). Also shown in Fig. 1 is the weighting function $\partial B_\nu/\partial T$ for a 250-eV blackbody distribution. As can be seen in the figure, the peak of the weighting function is fairly broad, and the integrand of Eq. (1) reaches its maximum at an energy corresponding to the minimum in the opacity between the N- and O-band absorption edges. In order to improve the efficiency of the hohlraum we need to blend in materials whose high-opacity regions compliment the low-opacity regions of the original material. Figure 1 also shows the calculated energy-dependent opacity for gadolinium, which was chosen because its regions of high opacity occur around the same energies as the holes in the Au opacity. For this model, the Rosseland mean opacity for Au is 823 cm^2/g, for gadolinium it is 455 cm^2/g, and for a 50/50 mixture of gold and gadolinium it is

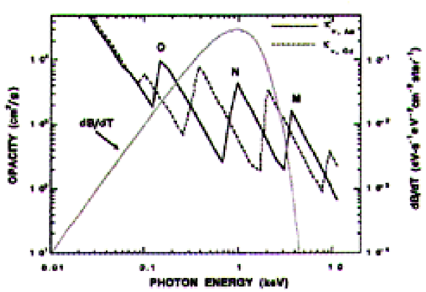
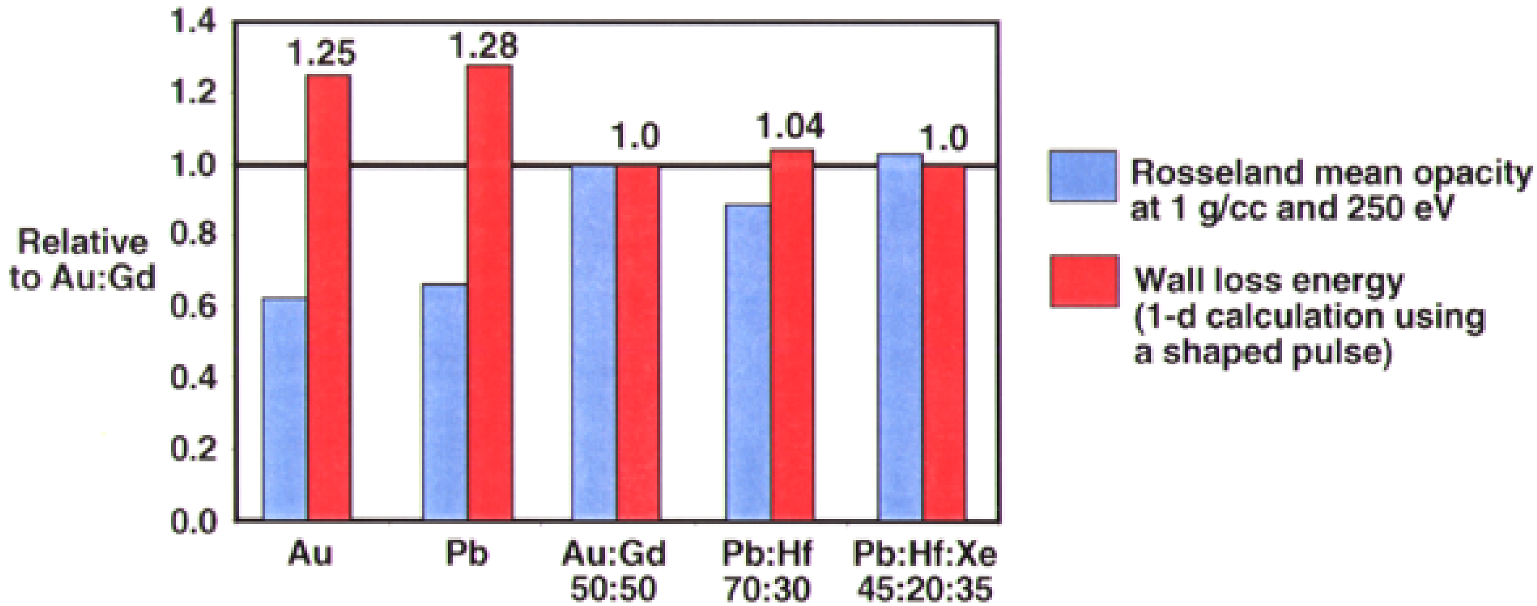


FIG. 1. Frequency dependent opacity of Au and Gd. Also shown is the weighting function $(\partial B/\partial T)$ corresponding to a 250-eV Planckian distribution.

Low activation materials can have wall losses comparable to the best materials



- A 4% increase in the wall loss → 60 kJ extra beam energy
  → 2% decrease in gain

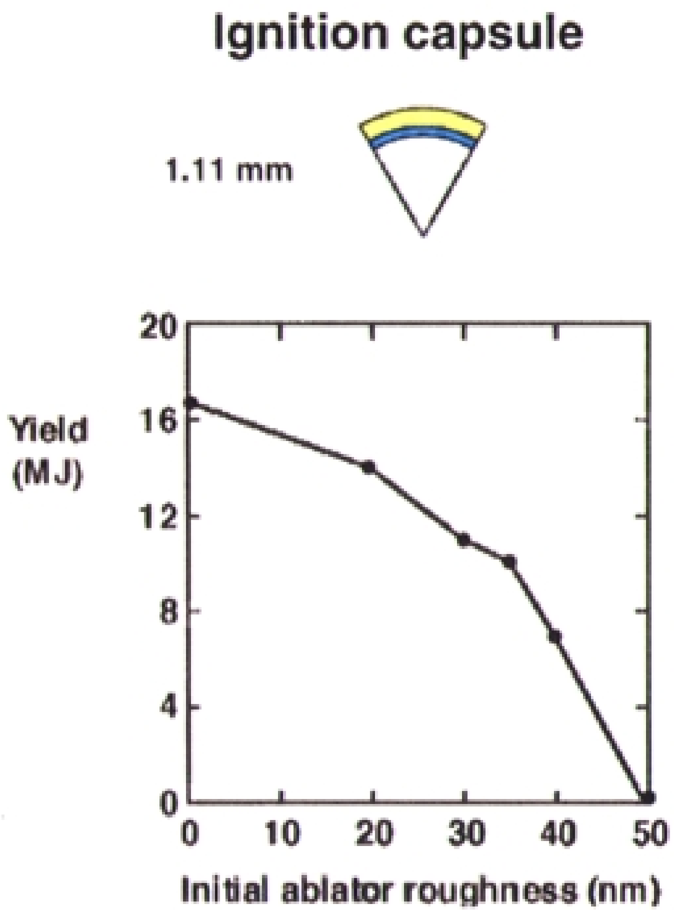
- Adding Xe gives the same wall loss as AuGd, but is more difficult to fabricate

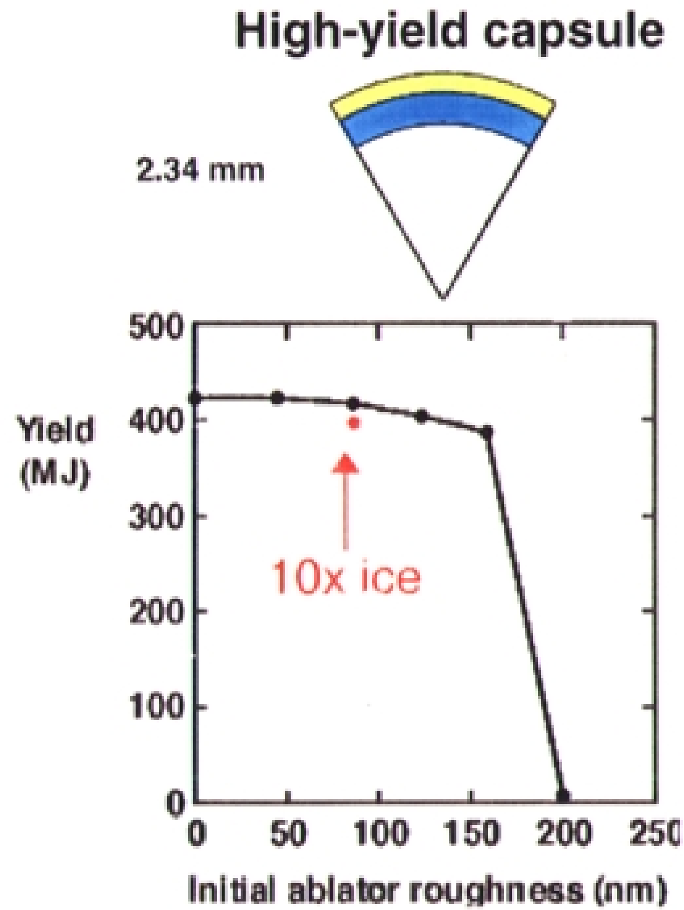
With the same surface finish high-yield targets are much less affected by perturbations than ignition-scale targets

Ignition High Yield
@ peak v

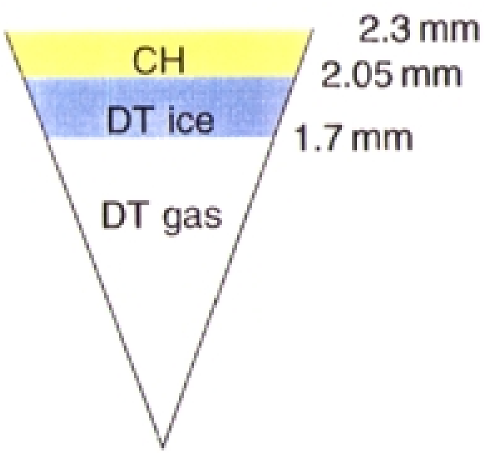
Ignition High Yield
@ ignition

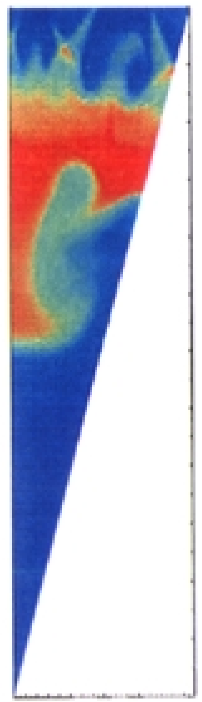
Scan vs. ablator roughness shows high-yield Be capsules are more robust than ignition-scale capsules

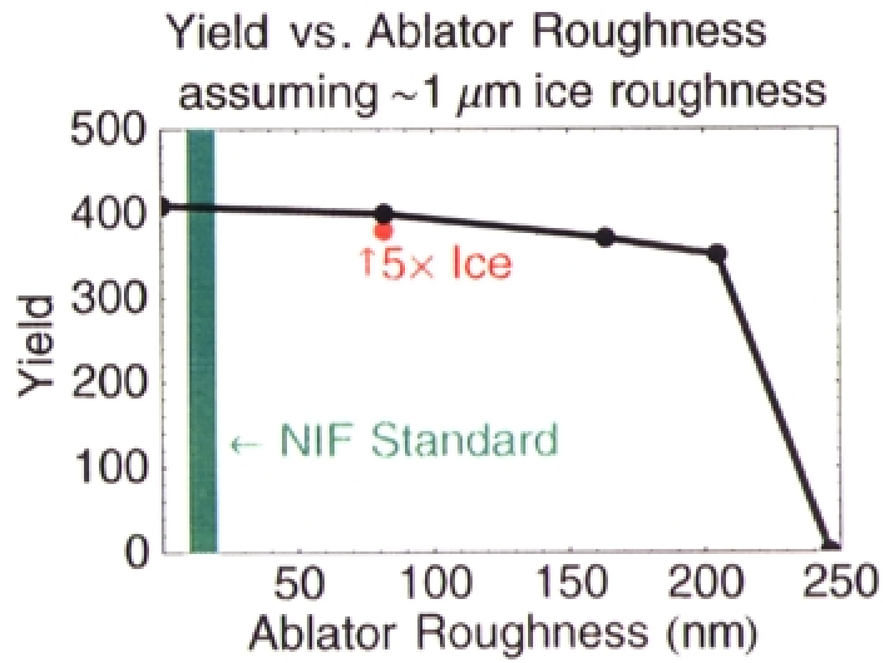




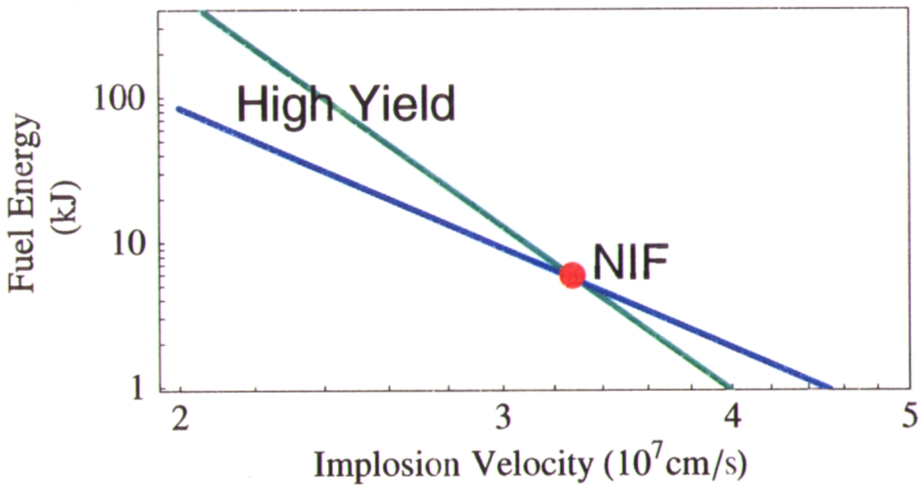
We have designed a plastic ablator capsule for HIF which is robust enough to handle current estimates of surface roughness







How much energy is needed to ignite a high yield ICF capsule?



- **Levedahl and Lindl**

  P constant

$$E_{ign} \sim \alpha_{if}^{1.7} v^{-5.5}$$

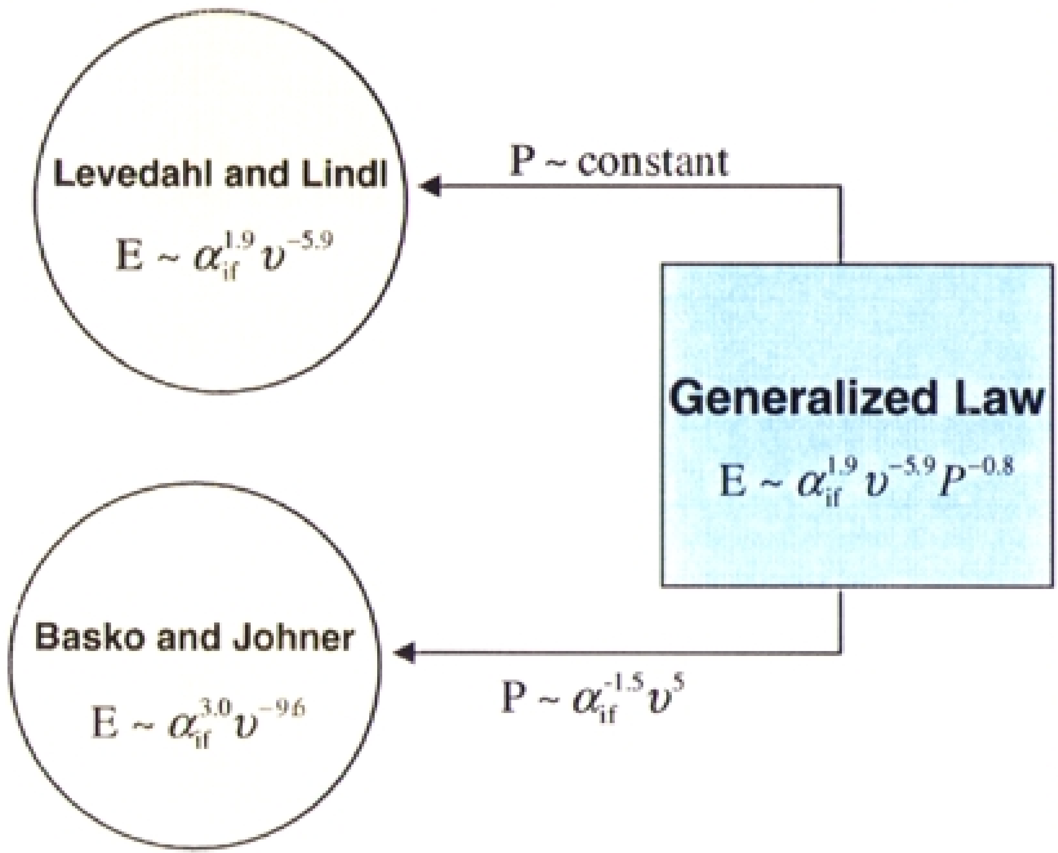
- **Basko and Johner**

$$P \sim \alpha_{if}^{-1.5} v^{5}$$

$$E_{ign} \sim \alpha_{if}^{3.0} v^{-9.1}$$

This difference is important to resolve for IFE

We have a generalized scaling law for the ignition energy which explains this difference



We created a large database of capsule implosions, and determined a generalized scaling law

We find that the drive pressure significantly affects the amount of energy required for ignition

We are studying a variety of target physics issues that have applications to IFE

- A new hybrid heavy ion target allows larger beam spots which are easier for the accelerator
  - This target introduces new target physics issues in radiation transport, hydrodynamics, and ion beam stopping

- Hohlraum wall mixtures made from low activation materials can also have a high opacity and low heat capacity needed to minimize wall loss

- High yield capsules are less sensitive to Rayleigh-Taylor instability growth allowing rougher surfaces than ignition-scale (NIF) targets

- Fundamental scaling laws for determining the amount of energy needed to ignite a capsule are being studied to guide the design of high yield capsules